Mechanical Engineering Doctoral Defense

Magnetic Needle Steering for Medical Applications

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Abstract

Many medical procedures, like surgeries, deal with the physical manipulation of sensitive internal tissues. Over time, new medical tools and techniques have been developed to improve the safety and efficacy of these procedures. Despite the leaps and bounds of progress made up to the present day, three major obstacles (among others) persist, bleeding, pain, and the risk of infection. Advances in minimally invasive treatments have transformed many formerly risky surgical procedures into very safe and highly successful routines. Minimally invasive surgeries are characterized by small incision profiles compared to the large incisions in open surgeries, minimizing the aforementioned issues. Minimally invasive procedures lead to several benefits, such as shorter recovery time, fewer complications, and less postoperative pain.

In minimally invasive surgery, doctors use various techniques to operate with less damage to the body than open surgery. Today, these procedures have an established, successful history and promising future. Steerable needles are one of the tools proposed for minimally invasive operations. Needle steering is a method for guiding a long, flexible needle through curved paths to reach targets deep in the body, eliminating the need for large incisions.

In this dissertation, we present a new needle steering technology: magnetic needle steering. This technology is proposed to address the limitations of conventional needle steering that hindered its clinical applications. Magnetic needle steering eliminates excessive tissue damage, restrictions of the minimum radius of curvature, and the need for a complex nonlinear model, to name a few. It also allows fabricating the needle shaft out of soft and tissue-compliant materials.

This is achieved by first developing an electromagnetic coil system capable of producing desired magnetic fields and gradients; then, a magnetically actuated needle is designed, and its effectiveness is experimentally evaluated. Afterward, the scalability of this technique was tested using permanent magnets controlled with a robotic arm. Furthermore, different configurations of permanent magnets and their influence on the magnetic field are investigated, enabling the possibility of designing a desired magnetic field for a specific surgical procedure and operation on a particular organ. Finally, potential future directions towards animal studies and clinical trials are discussed.

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